METHOD AND APPARATUS FOR SENSING POSITIONS OF DEVICE ENCLOSURES WITHIN MULTI-SHELF CABINETS

BACKGROUND OF THE INVENTION

Field of the Invention.

The present invention relates, in general, to computer systems and mass data storage systems and subsystems, and

5   more particularly, to a position sensing system and method for use in automatically and passively determining physical locations of device or other enclosures within data storage system racks or cabinets having multiple shelves or enclosures.

10   ### Relevant Background.

In the computer industry, there is ongoing and increasing demand for data storage systems with more capacity as well as improved reliability. The use of RAID (Redundant Arrays of Inexpensive Disks) systems has

15   significantly enhanced data storage reliability by providing redundancy, i.e., failure of one system component does not cause loss of data or failure of the entire system. Although initially RAID systems generally provided redundant disk drives, more functional redundancy has recently been

20   provided by extending redundancy to device enclosures. These enclosures may include a number of components such as power supplies, cooling modules, disk devices, temperature sensors, audible and/or visible alarms, and RAID and other controllers. To provide functional redundancy, the

25   enclosure typically includes an extra one of each of these components that is needed for proper functionality. For

1

example, two power supply units may be provided such that if one fails the remaining power supply unit is capable of providing adequate power.

A data storage system, e.g., an enterprise data center or complex, includes numerous multi-shelf cabinets or racks each holding multiple enclosures. The system is adapted for replacement of individual enclosures to upgrade or modify the system or in some cases, to service an enclosure. If an enclosure no longer has functional redundancy, e.g., one of its power supplies has failed, a system administrator will replace the entire enclosure or the failed power supply. To facilitate replacing or otherwise servicing enclosures, it is necessary to first identify the physical location and operating status of each enclosure within each cabinet and more specifically, to view the location and status of each enclosure on a monitor and/or graphical user interface (GUI).

Previously, the physical locations of components, such as enclosures, in data storage systems have been entered into databases used by monitoring software to display the location to the system administrator on the GUI. However, the manual entry process is susceptible to human error in initially entering the data and in updating the location information as the system is modified and grows in number of cabinets and enclosures in each cabinet. If the location is incorrect, the administrator most likely will remove and replace the wrong enclosure. Efforts to use analog sampling and polling have resulted in improved position detection within systems but have not been without problems due to noise, linking to fibre channel loop addressing, and added software monitoring complexity.

2

Hence, there remains a need for an improved method and apparatus for identifying the physical location of each enclosure in a data storage system. Preferably, such a system would support field replacement of individual

5   enclosures, would not interfere or reduce data transfer or other functionality of the enclosures or included components, and would provide enclosure, shelf, and cabinet identification information for each enclosure within a system independent of its address on a fibre channel loop.

10   **SUMMARY OF THE INVENTION**

The present invention addresses the above discussed and additional problems by providing a cabinet for physically storing and communicatively linking computing devices. The cabinet includes shelves adapted for racking or holding

15   device enclosures. Significantly, the cabinet includes a cabinet cable linked to each of the shelves that is adapted to provide a unique shelf identifier signal to each of the shelves. To allow an enclosure to be located within a data storage system having numerous cabinets, the cabinet

20   includes a device, such as a cabinet environmental monitoring unit (EMU), for providing information identifying the cabinet to each of the shelves (such as a unique cabinet number). The cabinet cable is made up of a plurality of serially connected junction boxes each including a first set

25   of sensing wires and a second set of sensing wires. A side connector is also included in the cable and linked to one of the shelves for providing the shelf identifier signal from the first and second sets of sensing wires.

To provide a different shelf identifier signal at each

30   junction box, the junction boxes are wired such that each of the sensing wires in the first set are moved one position

3

and each of the sensing wires in the second set are moved one position prior to the connection to an adjacent junction box. In this fashion, the physical location of the shelf within the cabinet is identified by its connection point along the cable. To allow each of the junction boxes to provide unique identifiers to two shelves, each junction box further includes an additional side connector linked to the first and second sets of sensing wires and an additional sensing wire that is linked to the side connectors. This additional sensing wire is alternately grounded and ungrounded at each side connector to alter the shelf identifier signal. In one embodiment, it has proven useful to have the first set of wires include 3 sensing wires and the second set of wires include 4 sensing wires to provide at least 24 of the unique shelf identifier signals within the cabinet cable and up to 48 in some situations.

In service, the cabinet typically includes a device enclosure on one of the shelves comprising a processor, such as an EMU, for processing the unique shelf identifier to determine a physical location within the cabinet. The processor generally then includes the determined physical location and the cabinet identification information in messages transmitted outside the enclosure to allow quick identification and mapping of every enclosure within a data storage system. The processor can determine the physical location by retrieving a shelf identifier from enclosure memory using the received shelf identifier signal. In one embodiment, the received shelf identifier signal is a 8-bit signal that is converted to a 4-bit shelf identifier by the processor for inclusion in messages along with the cabinet identification information.

4

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an illustration of a data storage system or complex with cabinets having multiple shelves incorporating a cabinet bus that provides, at least in part, the position detection techniques of the present invention;

FIG. 2 is a simplified block diagram of an exemplary device enclosure that may be positioned on a shelf of the cabinets of FIG. 1 and for which a physical position can be sensed by the data storage system;

FIG. 3 is a wiring diagram of a portion of a cabinet cable illustrating the 3-4 wiring arrangement used in one embodiment of the invention to provide unique digital identifiers to each shelf location in a cabinet;

FIG. 4 is a table illustrating shelf identifiers obtained using an eight-wire arrangement in a cabinet bus with 3U shelf spacing; and

FIG. 5 is a table similar to that of FIG. 4 illustrating shelf identifiers obtained in an alternative eight-wire arrangement in a cabinet bus to support 1U shelf spacing.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention is a system and method of determining or sensing the position of an enclosure or other device within a multi-shelf cabinet and within a storage complex utilizing a plurality of such cabinets or racks. The invention involves using a uniquely designed cabinet bus or cable in each cabinet that is linked to each enclosure, e.g., to the environmental monitor processor or unit (EMU). The cabinet cable is divided into two sensing portions that

are used to provide position signals that give a unique identifier for each shelf location. The EMU is configured to receive and process the position signals from the sensing portions to define a physical location within a cabinet and the specific cabinet is determined from a cabinet identifier provided by another processor such as a cabinet EMU provided in each cabinet to facilitate intercabinet communications. In one embodiment, one sensing portion includes three wires and one portion includes four wires that when combined with a grounded wire provide an eight-bit shelf identifier that is arranged (with junction crossovers and other features explained below) to provide twenty-four unique shelf or cabinet position identifiers. The invention thus provides an electrically passive method of identifying the location of each enclosure on a shelf within a data storage complex, i.e., by shelf and cabinet identifiers. Thus, the invention provides a method and system that requires no active members (other than active components in enclosure EMUs as discussed below that can be replaced) in the cable or bus itself, thereby significantly enhancing system reliability.

Figure 1 illustrates a data storage system 10 that provides components that function in combination to provide the enclosure position sensing features of the present invention. As shown, the data storage system 10 has a first and second cabinet 20, 50 (although typical systems 10 may have many more cabinets 20, 50) each having a plurality of shelves 24, 54. The shelves 24, 54 or shelf locations are configured to allow an enclosure (such as the device enclosure 100 of Figure 2) or other components to be plugged into and supported within the cabinet 20, 50. Typical, cabinets 20, 50 configurations call for 14 shelves 24, 54

6

although more shelves may be provided such as up to 24 or
more shelves 24, 54. If shelves 24, 54 are arranged
vertically, a typical cabinet 20, 50 may have 24 shelves 24,
54 that each occupy a certain amount of rack space, such as

5   3 retma (U) which is a standard mounting unit increment.

        Each shelf 24, 54 (and more particularly, the enclosure
100 at a shelf location 24, 54) is linked to a fibre channel
loop 28, 58 that enables access by and data flow to a host
computer 30, 40. The data that is passed typically includes

10   SCSI-3 Enclosure Services (SES) data and commands sets and
importantly, includes position information that identifies
the shelf position and cabinet number or other identifier.
The host computer 30, 40 may be a personal computer (PC), a
server, or other computer or electronic device running

15   software for allowing a user to access the position
information (i.e., to receive the position information or
signals from the fibre channel loops 28, 58 and display or
otherwise provide enclosure position information to the
user). In one embodiment, the host computer 30, 40 includes

20   a monitor 32, 42 and provides enclosure position information
on via a graphical user interface (GUI) 34, 44. The host
computers 30, 40 are further linked to a communication
network or bus, such as a company Ethernet, intranet, and
the like, to allow information from enclosures on the

25   shelves 24, 54 to be requested, retrieved, and transmitted
to users at a location remote from the cabinets 20, 50.

        Significantly, the cabinets 20, 50 include cabinet
busses 60, 62 that are configured to passively provide
electrical signals to enclosures on the shelves 24, 54 that

30   uniquely identifies the position (typically vertical) within
the cabinet 20, 50. The cabinet busses 60, 62 also provide

7

an out-of-band (external to any fibre loop) communication
path between the shelves 24, 54. The cabinet busses 60, 62
are divided into a number of junction boxes 66, 68. As
shown, each junction box 66, 68 is linked to two shelves 24,

5   54. Each junction box 66, 68 includes four connectors, such
as RJ-45 connectors, for connection to the shelves 24, 54
and adjacent junction boxes 66, 68 and/or terminators. The
busses 60, 62 further include a top terminator 70, 72, and a
bottom terminator 74, 76. The cabinet bus 60, 62 components

10   are explained in more detail with reference to Figure 3 that
illustrates an exemplary wiring arrangement for a portion of
the busses 60, 62.

In the illustrated embodiment, each cabinet 20, 50
includes a cabinet EMU 86, 88 that provides cabinet

15   information such as a cabinet identifier, cabinet type, and
the like that is passed via the cabinet bus 60, 62 to the
shelves 24, 54 for use by an enclosure in sensing or
determining position of the enclosure within the system 10.
The cabinet EMUs 86, 88 are optional but when included, the

20   bottom terminators 74, 76 are not required and are not
included in the cabinet busses 60, 62, and the cabinet EMUs
86, 88 are adapted to provide the termination feature(s).
In multi-cabinet systems 10, the cabinet EMU 86, 88
typically also acts as a firewall and router for SES

25   information. In this regard, the cabinet EMU 86, 88 is
linked to a communication link or network 98 (such as a
private Ethernet) that allows the EMU 86, 88 to broadcast
SES data for all shelves or groups of shelves 24, 54 to
other cabinet EMUs 86, 88. The cabinet EMU 86, 88 filters

30   the received SES data and forwarded to the corresponding
enclosures on shelves 24, 54 by group (e.g., the received

8

SES data is rebroadcast via the cabinet bus 60, 62). The cabinet EMU also transmits signals to the cabinet LED display (and audio alarm) 94, 96 for displaying status information for enclosures on the shelves 24, 54.

5   Figure 2 illustrates an exemplary device enclosure 100 that according to the invention is configured to receive passive position signals from the cabinet bus 60, 62, process the signals including the cabinet identifier from the cabinet EMU 86, 88 (or another component), and transmit
10   the enclosure position information in a signal to the host computer 30 (or 40). Note, the term shelf is often used for components within a cabinet 20, 50 such as an enclosure 100. In this application, shelf and shelf position is being used to identify a location, e.g., a vertical position, within a
15   cabinet 20, 50 at which an enclosure 100 or other component(s) is connected or plugged in to the system 10.

        The GUI host 30, 40 refers generally to any controller or host adapter capable of processing enclosure position signals and displaying (or otherwise reporting) the
20   enclosure position to a user. The host typically will also be used to communicate SES data or pages via the fibre channel loop 28, 58 to and from the cabinets 20, 50. The highlighted path from the GUI host 30, 40 is used to show one exemplary path in the enclosure 100 for such SES data.
25   The enclosure 100 is also linked directly to the cabinet bus 60, 62 to receive the cabinet identifier and shelf position information or identifier from the bus 60, 62 (as explained below).

        The enclosure 100 includes an input/output (I/O) module
30   104 linked to the fibre channel loop 28, 58. The fibre channel loop 28, 58 is typically an arbitrated loop and

9

although this diagram only shows one loop 28, 58 passing to
(as shown by lines 108 with one data path through a disk
drive 116 shown) the I/O module 104, the enclosure 100 may
have two redundant loops with two I/O modules 104. The I/O

5   module 104 acts as a communication interface to a plurality
of disk devices or disk drives 116. Each I/O module 104
includes a bypass circuit 112 for each disk drive 116. The
bypass circuit 112 can redirect the fibre loop 108 to
include or exclude the disk drive 116 in the loop 108. If

10   an EMU 130 is included in the enclosure 100, the EMU 130 can
be used to control the bypass circuits 112 via the 12C bus
160 and I/O module 104. If no EMU 130 is present, the I/O
modules can be configured to control the bypass circuits
112.

15   A number of standard disk devices may be utilized for
the disk drives 116 to practice the invention. For example,
in one embodiment, the disk drives 116 are selected to
conform to the "Enclosure Initiated ESI" option described in
the "SFF Committee, SFF-8067 Specification for 40-pin SCA-2

20   Connector w/Bi-directional ESI," Rev. 2.6, November 19,
1999. An Enclosure Services Interface (ESI) bus 120 is
provided to facilitate position and SES data to be passed
between the EMU 130 and the GUI host 30, 40. Preferably,
the ESI bus 120 functions to allow the EMU 130 to provide

25   enclosure position and SES data signals without occupying an
address on the fibre channel loop 108 (although in some
embodiments the EMU 130 may be directly linked to the host
30, 40).

As shown, the enclosure 100 includes an EMU 130 that

30   primarily functions to process and broadcast SES data to
either the GUI host 30, 40 and/or the cabinet EMU 86, 88.

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Significantly, the EMU 130 also functions to process and forward passive shelf identifier information and cabinet identifier information from the cabinet bus 60, 62. To this end, the EMU 130 includes an ESI controller 132, an EMU

5 processor or CPU 134 (linked via I/O latch 158 to the cabinet bus 60, 62), and a controller area network (CAN) bus controller 156. Memory is provided for use by the CPU 134, and may take many forms such as that illustrated of RAM 138 (such as 256 K), flash memory 140 (such as 512 K), and

10 EEPROM 142 (such as 2 K). Figure 2 illustrates the cabinet cable or bus 60, 62 connected to the CAN bus controller 156 to allow the EMU 130 to obtain the shelf identifier signal and obtain CAN signals. In other embodiments not shown, the EMU 130 or other enclosure processor may obtain the shelf

15 identifier or number from other wires on the cabinet bus 60, 62 connected to other components of the EMU 130 of the enclosure 100.

The EMU 130 further includes memory 144 in the form of ¼ K EEPROM that is typical of many printed circuit

20 assemblies and may be used by the EMU 130 for storage of type and revision information, worldwide names, serial numbers, and similar information. LED controls 146 and an input and output display 148 are provided for operation by the EMU CPU 134. An I2C controller 150 and temperature

25 sensor 152 are provided and linked to the I2C bus 160 which provides a communication path for the EMU 130 to receive status information from and to send control information to all of the elements of the enclosure 100. The enclosure 100 further includes I/O module 104, memory 162 and backplane

30 memory 164 linked to the I2C bus 160. Redundant power supplies 166, 168 are also provided and linked to the I2C

11

bus 160. A LCD panel 170 for the enclosure 100 may also be provided and linked (by a RJ-45 connector or otherwise) to the I2C bus 160 for receiving control signals from the EMU 130.

5   According to an important aspect of the invention, the enclosure 100 passively receives electrical signals that it uses to determine a unique digital identifier for the shelf 24, 54 upon which the enclosure is positioned. This is achieved with the use of the cabinet bus 60, 62 that
10   includes a series of junction boxes 66, 68 that each provide a unique shelf identifier for a set of shelves 24, 54 (such as for 2 shelves). The cabinet bus 60, 62 is comprised, in part, of wires that are divided into sensing sets or groups that work in combination to provide a single position signal
15   that identifies the shelf 24, 54 (e.g., vertical position within the cabinet 20, 50). Two sensing sets are used along with alternate grounding and wire crossover between junction boxes 66, 68 to provide the passive signaling of shelf identifiers. Depending on the number of shelves 24, 54 to
20   be identified in a cabinet 20, 50, numerous combinations of numbers of wires in each sensing set may be used such as sets of 5 and 2, 4 and 3, and the like.

     Figure 3 shows one preferred embodiment of a cabinet bus 60 that provides 24 unique shelf identifiers (as shown
25   in tabular form in Figure 4). A small portion of the cabinet bus 60 is provided illustrating only two junction boxes 66 although the number of junction boxes 66 typically will range between 7 and 12 for most cabinets 20, 50 to identify between 14 and 24 shelves 24, 54. The cabinet bus
30   60 has two main purposes: provide an identifier for an enclosure 100 location within the cabinet 20, 50 (such as

12

vertical position in distances in units of 3U from the
bottom of the cabinet 20, 50 and cabinet designation or
identifier) and provide a communications path between the
device enclosure EMUs 130 in the cabinet 20, 50 that does
5   not conflict or compete with the data path 108 to drives 116
within the enclosures 100. The combination of the shelf
location and cabinet designation provides complete enclosure
position information that allows complete mapping or
visualization of every enclosure 100 on shelves 24, 54 in
10   the data storage system 10.

      In the embodiment illustrated in Figure 3, a ten-wire
arrangement for the cabinet bus 60 is shown with seven wires
being dedicated to passively providing the shelf location to
the side connectors 82 in which enclosure 100 is connected
15   (such as to EMU 130 via CAN bus controller 156). As shown,
two wires are used for a CAN bus 178 and the remaining wire
is used as a ground for the cabinet bus 60. The
"horizontal" portion of the cabinet bus 60 is a stub that
taps off the "vertical" portion at a specific location for a
20   single shelf 24, 54.

      More specifically, the cabinet bus 60 is fabricated of
modular pieces called junction boxes 66. Each junction box
has four connectors 82, 84, such as RJ-45 connectors. Two
connectors 82 (side or transverse connectors) are stubs that
25   connect to two shelves 24, 54 (as shown with connectors 82,
84 to shelf 1 and shelf 2 for one junction box 66 and to
shelf 3 and 4 for the second junction box 66). The other
two connectors 82, 84 (end or inline connectors) function to
enable the junction boxes 66 to be daisy chained to adjacent
30   junction boxes 66 with an inter-junction cable 78, 80. In a
typical cabinet 20, 50, each junction box 66 serves 2

13

shelves (or 6U of height in a 3U spacing arrangement) within the cabinet 20, 50. To facilitate operation of the CAN bus 178, terminating resistors 172, 174 (such as 120 ohm resistors) are provided at each end of the active bus 178.

5   In one embodiment, the terminating resistors 172, 174 are contained in terminating plugs 70, 72 attached to the top and bottom junction boxes 66 in the cabinet bus 60.

The cabinet bus 60 includes a first and second sensing group of wires 180, 182 and a selectively grounded wire 184

10   that are dedicated to providing shelf identifier or position information to the side connectors 82 (and, connected enclosures 100). As shown, the first and second groups 180, 182 include a total of seven wires with the first group 180 including 4 wires and the second group 182 including 3

15   wires. At the bottom terminator 174 (in the bottom of the cabinet 20, 50), one wire from each group 180, 182 is grounded and the remaining wires in each group 180, 182 are left open or ungrounded. The signals from each wire in the groups 180, 182 are pulled up (and then combined and

20   processed) in each EMU 130 in the shelves 24, 54 via the side connectors 82. The illustrated embodiment of cabinet bus 60 shows the starting bits (i.e., 7-bit initial ID) of an identifier signal being "OOGOOOG" (for open (O) or a 1 bit and ground (G) or a 0 bit) when the two sensing groups

25   180, 182 signals are combined sequentially (group 182 followed by group 180).

An eighth sense wire 184 is provided and added to the horizontal stub for each shelf 24, 54 in each junction box 66 (as shown, twice for each box 66). The additional sense

30   wire 184 provides a binary value (or final bit) that is alternately grounded within each junction box 66 to provide

14

a unique shelf identifier (ID) for each shelf 24, 54 within a box 66. As shown, the sense wire 184 is grounded on the first portion of the junction box 66 at 186 prior to tying to the side connector 82 but left open in the second portion

5   of the junction box 66 prior to tying to the second side connector 82. In this example, the first shelf position identifier is the 8-bit ID of "OOOGOOGG" when the first and second sensing groups 180 and 182 are combined with the additional sense wire 184. The second shelf position

10   identifier is differentiated by leaving the sensing wire 184 ungrounded and becomes the 8-bit ID of "OOOGOOGO." In this manner, the passive position sensing method of the present invention is able to uniquely identify each shelf 24, 54 in each junction box 66 although the same signal originates

15   (from the starting 7-bit identifier) in the combination of the two sensing groups 180, 182.

To provide a unique identifier (e.g., 7-bit identifier) to each junction box 66, the passive numbering scheme utilizes numbers of wires for groups 180, 182 that are

20   relatively prime, such as 3 and 4 in the illustrated embodiment. Significantly, the lines within each group 180, 182 are rotated or crossed-over as shown at 190 and 192 after the final side connector and at least before the next connection to the next junction box 66. In other words,

25   each wire in each sensing group 180, 182 is moved one position within the group 180, 182 to present a new position code to the next junction box 66 along the cabinet bus 60 (including a last position to a first position). For example, as shown, the rotation or "next position" moving of

30   the wires in the groups at 190 causes the initial position

15

identifier signal to change from "GOOGOOO" to "OGOOGOO" and at 192 to change from "OGOOGOO" to "OOGOOGO."

In operation, the shelf ID is determined from the combined signals of the eight lines (TTL or other lines) of the first and second sensing groups 180, 182 and the additional sensing line 184 from the cabinet bus 60. The use of groupings of 3 and 4 lines (sets 182, 180) combined with an alternately grounded eighth line 184 provides 24 unique identifiers as shown in the table of Figure 4. Figure 4 further shows how for each segment of cable 60 corresponding to a junction box 66 the single binary bit of the alternating grounded wire 184 provides two unique shelf IDs. The larger cabinets 20, 50 generally have heights of less than about 42U, and each storage shelf 24, 54 occupies 3U with a pair of controller shelves/enclosures occupying another 3U of the cabinet height. Hence, typical cabinets 20, 50 contain 14 or less shelves 24, 54 and the 24 shelf IDs provided by the illustrated example is more than adequate.

In one embodiment, a shelf ID of "0" is reserved to indicate the actual shelf position cannot be determined. Shelf IDs of 1 to 14 shown in Figure 4 are used for shelves 24, 54 used for device enclosures 100 and indicate the height the shelf 24, 54 is from the bottom of the cabinet 20, 50. Shelf ID of "63" is reserved for a cabinet EMU with the other shelf IDs being reserved for expansion. As shown in the table of Figure 4, the position signal provided by the cable 60 can also indicate a cabinet cable 60 is disconnected which occurs whenever every wire in either of the sensing groups 180, 182 is left open or ungrounded.

16

The enclosure 130 with the CPU 134 can process the received shelf ID signal from the side connector 82 to quickly look up or otherwise determine the shelf ID (which is typically a number of distance unit, such as 3Us, from

5   the bottom of the cabinet 20, 50) and convert this to a four bit shelf ID (i.e., representing shelf IDs of 1 to 14). The cabinet identifier information, such as a cabinet number, from the cabinet EMU 86, 88, is unique number and in some embodiments is a unique 8-bit number. In operation, the EMU

10   130 operates to transmit the shelf ID and cabinet number in each message, such as in the message header, to allow the receiving device (e.g., the monitoring GUI host 30, 40 or another enclosure 100 in another cabinet 20, 50) to quickly identify and/or map the physical location of the enclosure

15   100 within the data storage system 10 by shelf 24, 54 and cabinet 20, 50. Of course, if no message is received from an EMU 130, the enclosure 100 is not present or in other words, if a shelf ID and cabinet number combination is not reported to the GUI host 30, 40 then that location would be

20   considered open or available.

Although the invention has been described and illustrated with a certain degree of particularity, it is understood that the present disclosure has been made only by way of example and that numerous changes in the combination

25   and arrangement of parts can be resorted to by those skilled in the art without departing from the spirit and scope of the invention, as hereinafter claimed. For example, the specific number of unique shelf identifiers provided by the cabinet bus 60 can readily be varied by changing the number

30   of wires in each sensing group 180, 182 and even the number of sensing groups 180, 182. Additionally, the use of more

17

than one alternatively grounded sense wire 184 would allow the number of unique identifiers for shelves to be increased. With the features of the passive position sensing method taught in this disclosure, those skilled in the art will be able to readily arrive at cabinet bus 60 configurations that provide unique shelf IDs for numerous shelves 24, 54 within a cabinet 20, 50, and these arrangements are considered to be fully within the breadth of this disclosure and the following claims.

Figure 5 provides another specific illustration of how the teaching of the invention can be readily expanded to other than 3U shelf-spacing arrangements. The table in Figure 5 illustrates shelf IDs that can be obtained to support a 1U shelf-spacing arrangement. As shown, one or two bits are grounded in each wiring group (such as groups 180 and 182) rather than just one as shown in Figure 3 with the other lines being left open in the bus 60, 62. The illustrated passive identifier scheme supports positioning or spacing of 1U within a cabinet having 48 or less shelves. Presently, the largest cabinets are 42U in height which can readily be supported by this alternative passive wiring scheme for cabinet bus 60, 62, but those skilled in the art will readily comprehend that the features of the 1U and 3U spacing embodiments can be applied to smaller and larger cabinets with the same or differing shelf spacing by varying the crossover techniques, by utilizing fewer or greater sense wires or groups of sense wires, and by using varied grounding schemes.